Breakdown of Optical Absorbance Universality in 2D Heterostructures

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The optical absorbance of monolayer graphene is commonly regarded as universal, $A \simeq \pi\alpha$, and additive in multilayer systems. Within the framework of Quarkbase Cosmology, optical absorbance arises from the coupling between transverse electromagnetic illumination and a confined longitudinal vacuum mode Ψ shaped by the two-dimensional lattice. This leads to a falsifiable prediction for 2D–2D heterostructures: the total absorbance is not the sum of the individual layer absorbances. Instead, an interference-like cross term appears, controlled by the relative Ψ-phase accumulated across the stack and by geometric mismatch between layers (interlayer spacing, twist angle, curvature or strain superperiod). The effect is most clearly exposed in graphene/BN/graphene stacks, where BN acts as a Ψ-wave spacer rather than a passive dielectric. The prediction can be tested purely optically and does not rely on transport measurements.

INTRODUCTION

The absorbance of monolayer graphene, $A \approx \pi\alpha \approx 2.3\%$, is often presented as a universal constant, independent of material parameters and geometry. This result is commonly extended to multilayer systems through simple additivity, where the total absorbance is assumed to be the sum of the contributions of each layer.

In Quarkbase Cosmology, this universality is only approximate. Optical absorption is interpreted as a manifestation of the interaction between incident electromagnetic radiation and a longitudinal vacuum pressure mode Ψ confined by the two-dimensional lattice. Since Ψ is sensitive to geometry and boundary conditions, deviations from strict universality are expected even at the monolayer level, and additivity must break down in vertically stacked heterostructures.

Here we formulate a minimal, falsifiable prediction for such a breakdown of absorbance universality in 2D heterostructures.

THEORETICAL FRAMEWORK

For a single two-dimensional layer, the absorbance is written as

$$A_1(\varepsilon) = A_0\,(1 + \kappa\varepsilon)\,, \tag{1}$$

where $A_0 \simeq \pi\alpha$ is the flat, strain-free reference value, ε is a geometric control parameter (strain or curvature proxy), and $\kappa \sim 10^{-2} - 10^{-3}$ is a dimensionless coefficient. This already implies that absorbance universality is approximate and geometry-dependent.

Consider now a heterostructure formed by two absorbing monolayers (1,2) separated by a two-dimensional spacer of effective thickness d (e.g., BN). In the Quarkbase picture, each layer constitutes a boundary condition for the Ψ field, and the stack acts as a vertical, parallel composition of Ψ cavities. The total absorbance must then be written as

$$A_{\rm tot}(\omega) = A_1(\omega) + A_2(\omega) + A_{\rm cross}(\omega), \tag{2}$$

where the cross term $A_{\rm cross}$ represents Ψ-mediated interference between the two layers.

A minimal parameterization of this term is

$$A_{\rm cross}(\omega) = 2\,\eta(\omega)\,\sqrt{A_1(\omega)A_2(\omega)}\cos[\Delta\phi_\Psi(\omega)]\,, \tag{3}$$

with $\eta(\omega) \in [0,1]$ an effective Ψ-coherence factor. The relative phase accumulated across the stack is given by

$$\Delta\phi_\Psi(\omega) \simeq k_\Psi(\omega)\,d + \phi_{\rm twist} + \phi_{\rm curv}, \tag{4}$$

where k_Ψ is the effective Ψ wave number in the spacer, and $\phi_{\rm twist}$, $\phi_{\rm curv}$ encode phase shifts induced by twist-angle mismatch and curvature or strain superlattices.

EXPERIMENTAL PROPOSAL

The canonical test system is graphene/BN/graphene. Three sample types are required: (i) monolayer graphene as a baseline, (ii) bilayer graphene as a control, and (iii) graphene/BN/graphene stacks with controlled BN thickness and twist angle.

Broadband optical measurements (micro-ellipsometry or transmission/reflection spectroscopy) are sufficient. The protocol consists of measuring $A_1(\omega)$, $A_2(\omega)$, and $A_{\rm tot}(\omega)$ on equivalent regions and extracting the residual

$$\Delta A(\omega) = A_{\rm tot}(\omega) - [A_1(\omega) + A_2(\omega)]\,. \tag{5}$$

Within Quarkbase Cosmology, $\Delta A(\omega)$ is not expected to vanish and must vary systematically with interlayer spacing, twist angle, or controlled curvature.

PREDICTED RESPONSE

The prediction yields three non-negotiable signatures: (i) non-additivity of absorbance beyond conventional

thin-film optics, (ii) controllable modulation of ΔA through geometric parameters, and (iii) symmetry of the cross term, allowing either enhancement or suppression relative to simple additivity depending on $\cos(\Delta\phi_\Psi)$.

A strictly additive absorbance, once standard optical cavity effects are removed, would falsify the prediction.

CONCLUSION

Quarkbase Cosmology predicts a breakdown of optical absorbance universality in 2D heterostructures due to Ψ-mediated interlayer interference. The effect is purely optical, geometry-controlled, and experimentally accessible with existing instrumentation. Observation of a non-zero, geometry-dependent cross term in graphene-based stacks would directly challenge the assumption of absorbance universality and support a vacuum-pressure-field interpretation of light–matter interaction in two-dimensional systems.

[1] C. Omeñaca Prado, *Curvature-Tunable Absorbance in Graphene: A Quarkbase-Cosmology Prediction* (2025).
[2] C. Omeñaca Prado, *X-Fenes: Longitudinal Vacuum Modes Confined by 2D Crystals* (2025).